Satellite Remote Sensing of Coral Reefs

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By learning about coral reefs, students gain an understanding of ecosystems and how cutting-edge technology can be used to study ecological change

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Coral reefs are one of the most important ecosystems on the planet, providing sustenance to both marine organisms and humans. Yet they are also one of the most endangered ecosystems as coral reef coverage has declined dramatically in the past three decades. Researchers continually seek better ways to map coral reef coverage and monitor changes over time. In recent years, satellite remote sensing has become a popular and effective mapping tool for ecological studies, especially in marine science.

In this article we present a lesson plan for high school science students that demonstrates how marine scientists use satellite remote sensing to gather detailed information about coral reefs worldwide. Before discussing the lesson plan, we provide an in-depth review of both remote sensing and coral reefs.

What is remote sensing?

In the broadest of terms, *remote sensing* is the study of one location from a different location. Remote sensing involves gathering data using sensors located at some distance from the target of study. Various types of sensors are used in remote sensing, including acoustical (sonar) sensors, optical (visible spectrum and infrared) sensors, and radar. These sensors can be carried on ships, airplanes, satellites, and even balloons.

Certain satellite sensors measure the amount of light emitted and/or reflected from Earth's surface at specific wavelengths in the electromagnetic spectrum (Figure 1). A researcher then interprets the measurements and determines what the data may imply. A simple analogy is human vision: Humans use their eyes as sensors, which gather sight information; the information is then sent to the brain, which interprets what the eyes see.

Satellites provide an extraordinary amount of detailed information about Earth's surface. Scientists use this information for a variety of applications, such as managing renewable and nonrenewable resources. For example, scientists use satellites to measure a suite of environmental factors, including

- ocean color (a proxy for primary productivity),
- temperature (sea-surface and terrestrial),
- land cover and usage (e.g., human-made versus natural),
- benthic cover (underwater habitats),
- winds,
- topography and bathymetry, and
- hurricanes.

In fact, satellites provide the only tool to study processes that affect the entire planet at one time by giving researchers a way to see the whole Earth at one time. Certain satellites (e.g., Landsat) have been designed to look at Earth in small detailed pieces, specifically the terrestrial and coastal zones.

Landsat satellites

The first Landsat, launched in 1972, was primarily used to study agriculture and to determine the size and yield of a farm or field. Landsat 7, launched in 1999 by the National Aeronautic and Space Administration (NASA), is the current satellite and is often used for marine and coastal studies. The United States Geological Survey (USGS) is responsible for the archive of all Landsat data and has at least one cloudfree image of every known shallow-water coral reef in the world (approximately 1,500 images).

Landsat 7 follows a polar orbit (north–south) in conjunction with Earth's rotation (west–east). An orbit cycle is complete when the satellite retraces its path and passes over the same spot on Earth's surface. This takes 16 days and is termed the satellite's *temporal resolution*. Landsat 7 carries a sensor called the Enhanced Thematic Mapper Plus (ETM+), which has a *spatial resolution* or footprint, of 30 m. Therefore, any object smaller than 30 m cannot be detected or identified, as it is smaller than the footprint frame that encompasses that object. This means that when an image is displayed at full resolution, each pixel (picture element or smallest unit of an image) represents an area of 30 m × 30 m on the ground (image pixels are typically squares that depict a specific area on an image).

FIGURE 1

Electromagnetic spectrum.

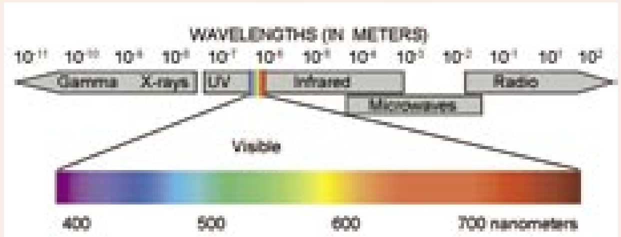
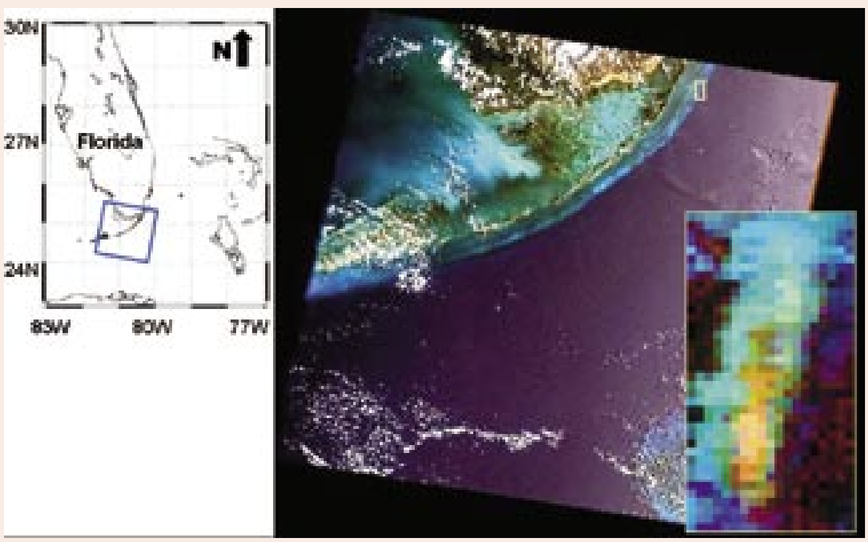


FIGURE 2

Landsat 7/ETM+ scene of the Florida Keys with location map (left) and zoomed view of Carysfort Reef, showing the 30 m x 30 m pixels (inset).



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To provide a sense of how big that is, the infield diamond of a baseball field is about 30 m × 30 m.

The ETM+ sensor has eight bands or channels, which means it collects eight images at once and each image highlights a specific section of the electromagnetic spectrum (Figure 1). The number of bands and the information they convey is described as *spectral resolution*. Three of the eight bands are in the visible range of the electromagnetic spectrum (400–700 nm)—the light visible by our own eyes.

In the marine environment, the water column absorbs red light almost immediately because red light has a longer wavelength. Blue light, on the other hand, has a shorter wavelength and penetrates deeper into the water column, which is why many underwater photographs have a blue or greenish tint to them. Because Landsat satellite images (Figure 2) have been gathered for many years, time-series data, or multiple images, can be used for various types of habitats around the world, including coral reefs. Landsat data can also be used to study coral reefs in remote areas that would be difficult to study any other way.

FIGURE 3

Close-up of Elliptical Star Coral (*Dichocoenia stokesii*) polyps.

(COURTESY OF CARL BEAVER, FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION.)

FIGURE 4

Colony of Boulder Star Coral (*Montastrea annularis*).

What are coral reefs?

Coral reefs are made up of several small (approximately 2 mm) animals known as coral polyps (Figure 3), which are related to sea anemones and jellyfish. Coral polyps create reefs when they bond to a hard substrate (e.g., limestone) and secrete a calcium carbonate skeleton. As one coral polyp dies another takes its place on top, thereby forming large coral colonies (Figure 4). A crosssection of coral reveals rows on top of rows of coral polyps, similar to the rings on a tree. The reef-building stony corals are known as hermatypic. However, not all corals are hermatypic. Corals such as sea fans and sea whips are soft and flexible like plants. Because they do not secrete a rigid limestone skeleton, they do not build reefs.

Most stony corals are actually colorless; they obtain their brilliant colors from the algae or zooxanthellae that live within their tissue. The photosynthetic zooxanthellae and the corals have a symbiotic relationship specifically known as mutualism, which means that each provides something beneficial to the other. In this case, corals (the animal) provide carbon dioxide and nutrients (in the form of waste) to the zooxanthellae (the plant), which then use the waste to provide oxygen and nutrients (in the form of sugars) to the coral. This relationship allows corals to thrive in clear, oligotrophic (low-nutrient) waters. The abundance of coral reefs are found between 30° north and 30° south latitude where there is plenty of sunlight, warm water (15–30°C), and normal marine salinity (33–37 ‰).

Why coral reefs?

Coral reefs are the most genetically diverse ecosystems in the world, as well as one of the most important. Although they cover a mere 1% of Earth's surface, they are home to nearly one-third of all marine species—the Great Barrier Reef is actually one of the world's largest natural features at more than 2300 km (1,350 miles). Reefs provide habitat, nurseries, and food for scores of marine species and even provide coastal protection from storms and hurricanes. For humans, they provide booming economies for commercial and recreational fishing, scuba diving, and tourism valued at an estimated $375 billion a year worldwide (Bryant et al. 1998). However, coral reefs face tremendous natural and anthropogenic threats (Wilkinson 2001). Current estimates predict that, if unchecked, coral reefs may suffer a worldwide decline of 60% by 2050 (Bryant et al. 1998). These are just a few of the reasons why it is critical to monitor the health of coral reefs. Unfortunately for a researcher, visiting reefs on a regular basis is both timeconsuming and expensive, especially reefs located long distances offshore. Remote sensing provides the opportunity for long-term, repetitive monitoring of these spectacular undersea communities.

FIGURE 5

Studying coral reefs with a remote sensing: A lesson plan.

The mission

In this activity, students will assume the role of marine scientists. Students will divide into research teams and map and monitor the habitats of a coral reef over an 18-year time period (five images). By matching the colors of the pixels to a selected benthic class (e.g., coral reef, sand, seagrass), students will classify the satellite image and produce a benthic habitat map (Figure 6, p. 55). Additionally, students will perform an accuracy assessment on their final habitat maps to see how close their results are to those of professional researchers. Students will access satellite images through the Institute for Marine Remote Sensing (IMaRS) website (*http://education.imars.usf.edu/coral_classification.doc*).

If computers are unavailable, it is also possible to perform this lab by using a color printout of the Landsat image, clear transparency sheets, and different color markers. Have students place the transparency over the Landsat image and color the pixels with the selected colors for each chosen class.

(Note: This activity is designed to take about three days of class time. Prior to this activity, you may want to review the electromagnetic spectrum, coral reef habitats, and some optics, which can be obtained from the websites listed in "On the web.")

Lesson plan

Materials

- Computers with internet access
- Purdue University's MultiSpec software. This software is free and requires only 1.8 MB of computer memory (available at *http://dynamo.ecn.purdue.edu/~biehl/MultiSpec*).

(Note: This experiment can also be done by hand with the use of a color printer, transparencies, and markers. This method requires students to color each of the pixels.)

Procedure

[A detailed step-by-step description of the methods is provided on the IMaRS website (*http://education.imars.usf.edu/coral_classification.doc*).]

Day one—Introduction to project:

- Assign students to five groups, each with their own coral reef year.
- Present the background information and key terms provided in this article and on the internet.
- Perform the "Light and Water" experiment provided on IMaRS website (optional).

Day two—On the web:

- Visit the IMaRS website for the data and other websites to gather more background information on the coral reef.
- Begin the study of the satellite imagery and decide the classifications and pixel color representation of those classes.

Day three—Classify:

- Classify the images.
- Produce a time series of classified images by bringing the groups together.
- Graph the results.
- Compare the results with those on the IMaRS website (accuracy assessment).

Topic questions

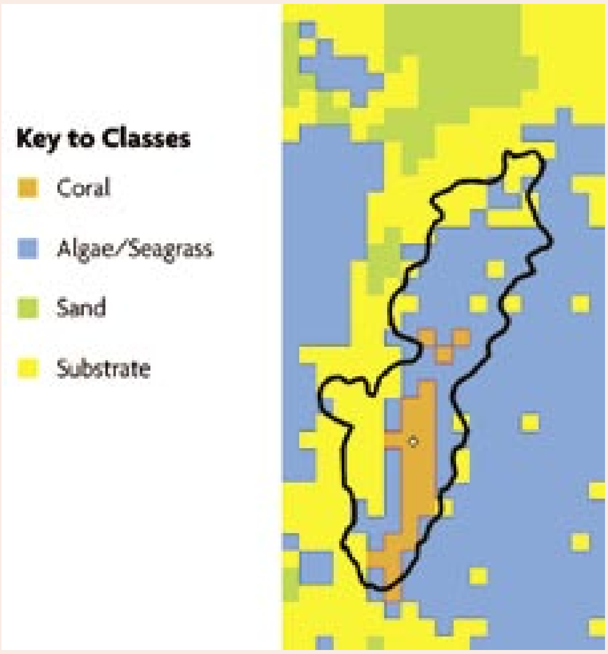
1. What changes did you see in the coral reef?
2. What may have caused those changes?
3. Do you think the changes were caused by human interaction with the ecosystem?
4. What difficulties did you have classifying the images?
5. Did certain classes "look" similar to other classes? Why? Did this "confuse" the software?
6. How did your classification images compare to those on the IMaRS website (accuracy assessment)?
7. If different, why?
8. Do you think that the changes you saw on your reef are representative of other coral reefs in the Florida Keys? Around the world?
9. What are some local, regional, and global causes of coral reef decline around the world?
10. What can you do to help make sure that coral reefs are around for future generations?

Studying coral reefs with remote sensing

In the lesson plan described in Figure 5, students use easily obtained satellite images to gain insight into two different facets of marine science—coral reefs and remote sensing. By learning about coral reefs, students will better understand the concept of ecosystems and how, in this case, outside forces can greatly alter an ecosystem as delicate as a coral reef. The remote sensing aspect of this lesson shows students how cutting-edge technology can be used to study ecological change. By combining these two fields, this lesson can be utilized for geography, geology, biology, or ecology studies.

FIGURE 6

Example of Landsat image after classification for Carysfort Reef (inside black line) for four classes.



A few simple tips will help this activity run smoother in the classroom. First, if teachers opt to use the free software, they must make sure that this software is preloaded onto any computer that will be running it. Teachers do not want to make the lesson an example of computer futility. This is especially relevant with older computers. Also, computer monitors should be checked for color accuracy, as many older monitors will alter the coloration of the Landsat coral reef image. Teachers must be comfortable with the software, and attempt to use other commands than those listed here so that when students begin to stray teachers can troubleshoot.

Stumbling points for students may arise when using the software, even though detailed step-by-step directions are provided. Many times this is due to the fact that many students are already computer savvy and step further ahead than they should.

The discussion of coral reef classification tends to become overly focused on the "little" things. For example, students have suggested the classification of fish or urchins. Teachers should remind them that the spatial resolution of Landsat is 30 m and this issue goes away. Also, when working on the classification, students should choose respective class colors *different* than those of the actual class constituents. For example, students should not use the color green for the "Algea/Seagrass" class. Choosing similar colors tends to cause confusion later in the lesson, specifically when discussing green habitats (i.e., seagrass) and the "green" class. Additionally, when making the comparison to the classified images on the IMaRS website (accuracy assessment), teachers should discuss how these classifications were performed in the very same manner as student maps were made, with one difference—actual field data was used to validate the maps (a true accuracy assessment).

After students study Carysfort Reef, they should look at other coral reef sites around the world for time-series information. There are several government, nongovernment, and academic organizations around the world that post coral reef surveys and images online (see "On the web").

Coral reefs are declining worldwide. Remote sensing is one tool uniquely capable of providing data for coral reefs at the global scale. This lesson plan aims to inspire students and teachers to become more aware of these two facets of marine science; one an ecological habitat and the other a tool to study that habitat. ■

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Wilkinson, C., ed. 2001. *Status of coral reefs of the world: 2000.* North Queensland, Australia: Australian Institute of Marine Science.

On the web

University of South Florida IMaRS: *http://imars.marine.usf.edu*

IMaRS Education Outreach: *http://education.imars.usf.edu*

University of South Florida Education Outreach: *http://marine.usf.edu/education-and-outreach/index.shtml*

NASA Landsat 7: *http://landsat.gsfc.nasa.gov*

NASA Education: *http://education.nasa.gov/home/index.html*

NASA Remote Sensing Tutorial: *http://rst.gsfc.nasa.gov/start.html*

USGS Landsat 7 Homepage: *http://landsat7.usgs.gov*

NOAA Coral Reef: *www.coralreef.noaa.gov*

Florida Marine Research Institute's Coral Reef: *www.floridamarine.org/features/category_main.asp?id=1340*

World Resources Institute, Reefs at Risk: *http://marine.wri.org//pubs_description.cfm?PubID=2901*

US Commission on Ocean Policy: *http://oceancommission.gov*